Foil heating and cooling; injection beam absorber (ACD)

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Fermilab

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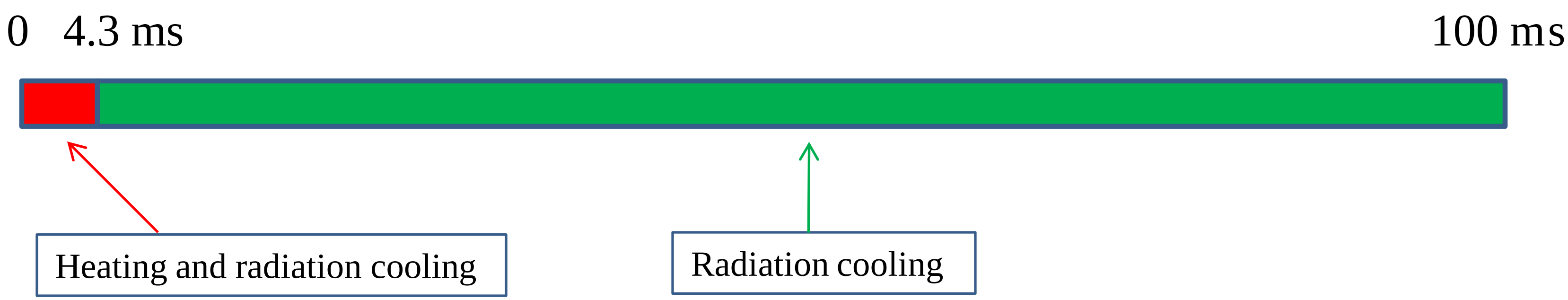
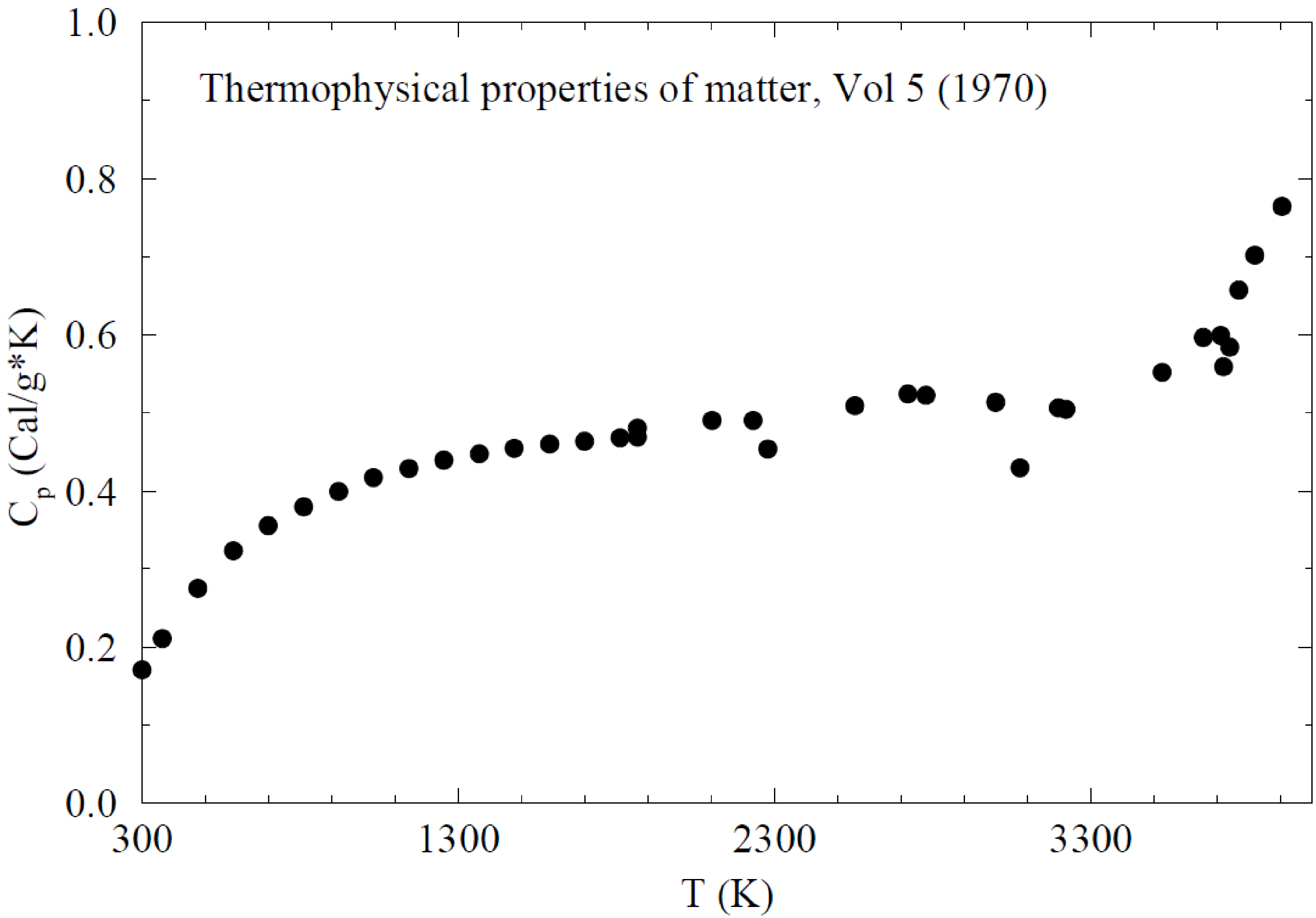
Foil heating and cooling



- Thermal analysis is performed for a single cycle (4.284 msec) with subsequent **radiation cooling** until next cycle.
- The hottest spot with linear dimension ≈ 0.3 mm (codes STRUCT/ORBIT)
- Heat ***conduction*** in the foil is ***ignored*** (ANSYS is not used)
- 2.67E13 proton/cycle @ 10 Hz → **2.67E14 proton/sec**
- $$\frac{\partial T}{\partial t} = \frac{N}{\rho c_p}\left|\frac{dE}{dz}\right| - \frac{\varepsilon \sigma_{SB}}{\Delta z \rho c_p}(T^4 - T_0^4) \qquad 0 \le \mathrm{t} \le \tau_{\mathrm{p}}$$
- $$\frac{\partial T}{\partial t} = -\frac{\varepsilon \sigma_{SB}}{\Delta z \rho c_p}(T^4 - T_0^4) \qquad \tau_{\mathrm{p}} \le \mathrm{t} \le \tau$$

Measured dependence of specific heat, c_p, on T (graphite)



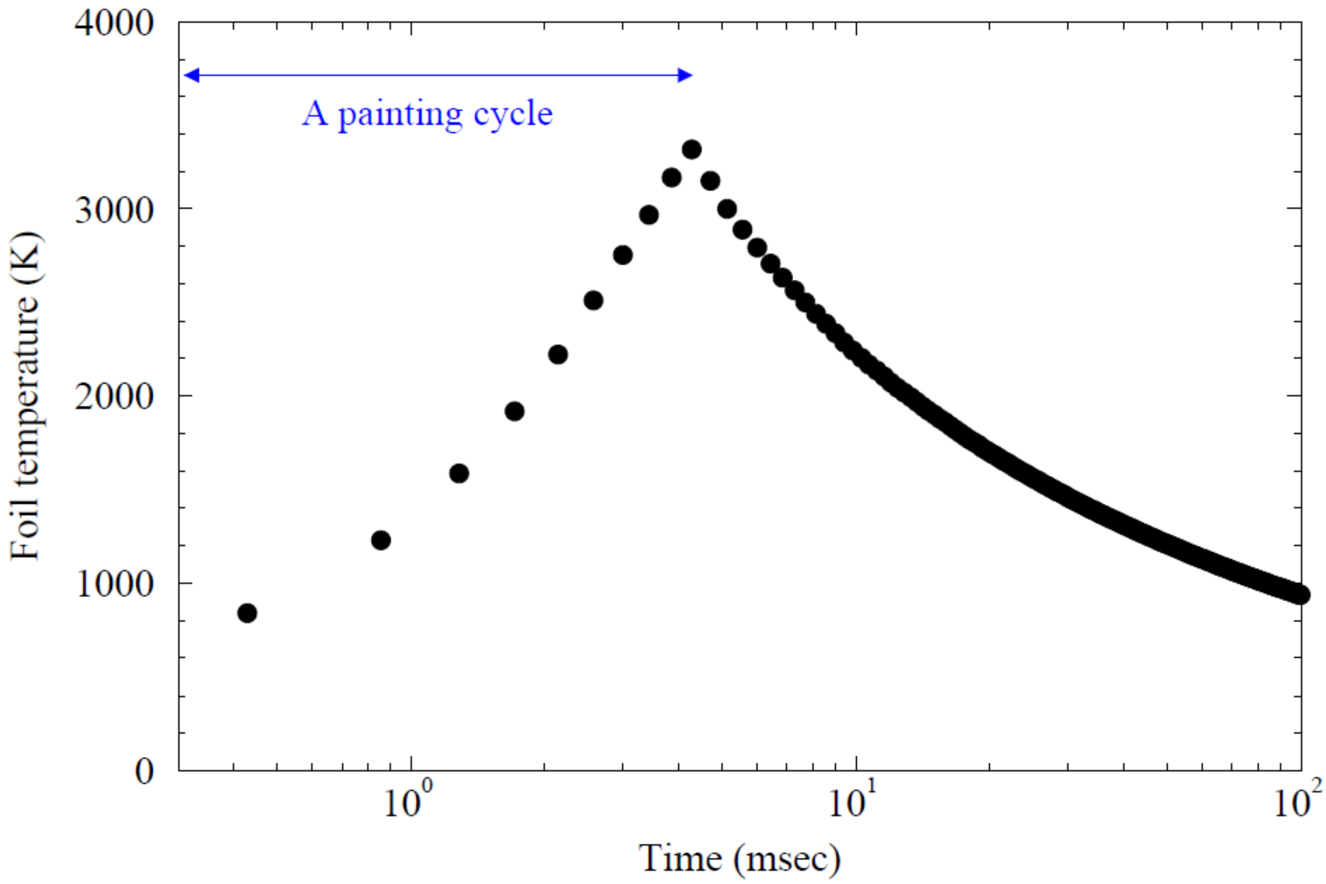
Foil heating and cooling

- Valeri Lebedev suggested taking into account that a fraction of generated **δ-electrons** will escape the foil thus reducing the amount of deposited energy. And the foil can be rotated by, e.g. 45 degrees, relative to the beam → extra reduction factor of 1.4 due to increased area of the hottest spot.

- Detailed calculation of the fraction was performed with **MCNPX 2.6** code. It allows us to track electrons (and secondary photons) down to **1 keV**. (Range of 1-keV electrons is approximately 1% of the foil thickness.) In this calculation uniform spatial distribution of generated **δ-electrons** was used. Realistic energy and angular distributions were employed.

- According to **MCNPX 2.6**, **23%** of energy deposited in the 600-μg/cm^2 carbon foil by 2-GeV protons due to ionization (dE/dx) will be taken away by the **δ-electrons**. That is, **77%** of the initially deposited energy will give rise to the foil heating.

Foil temperature without rotation

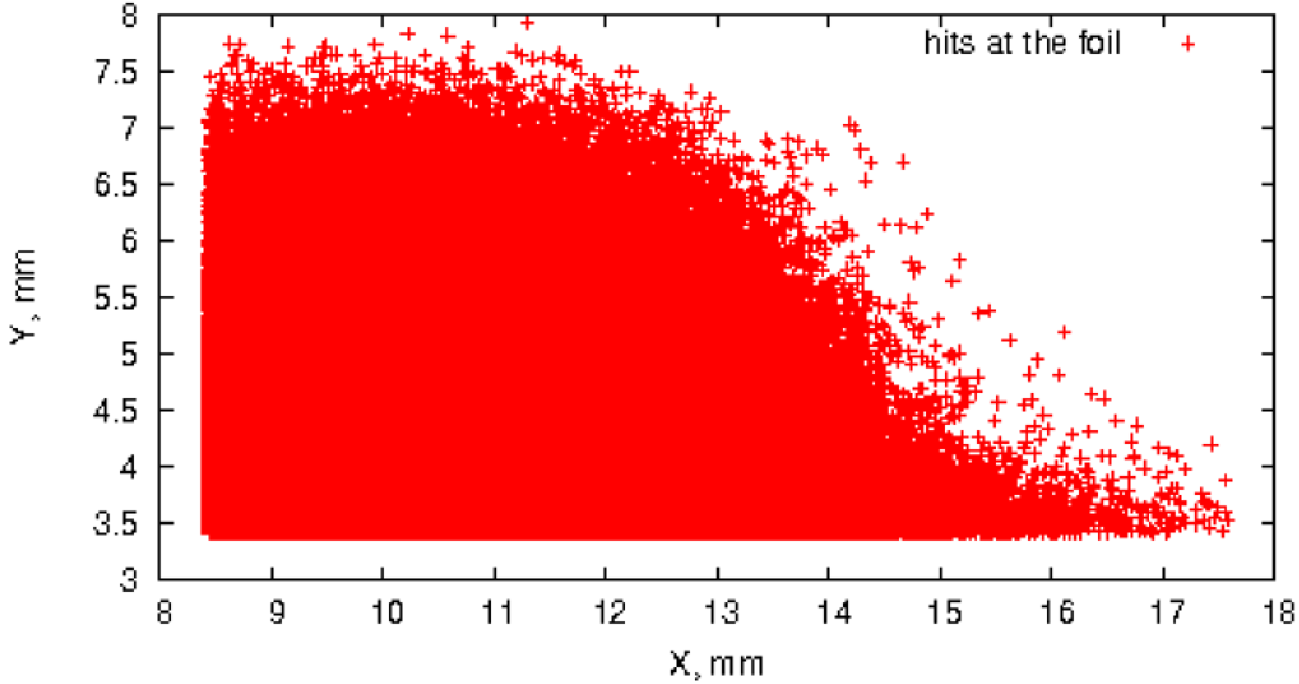


Foil rotation → T_{max} / 1.4 = 3320 / 1.4 ≈ 2350 K → **ANSYS can help**

Injection beam absorber

- Calculations with **STRUCT** and **MARS** codes
- Surface water activation
- Power density in magnet coils
- Residual activation
- Beam parameters: **2.67 10^{13} 2-GeV proton/pulse @ 10 Hz**; Beam power **85 kW**

Example of STRUCT output which serves as an input to MARS code

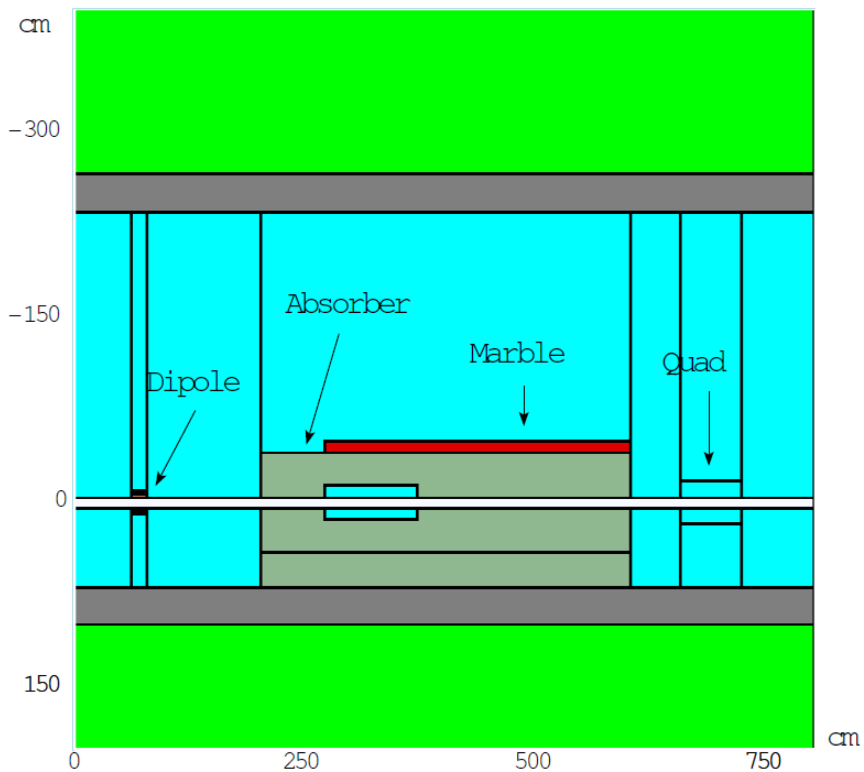


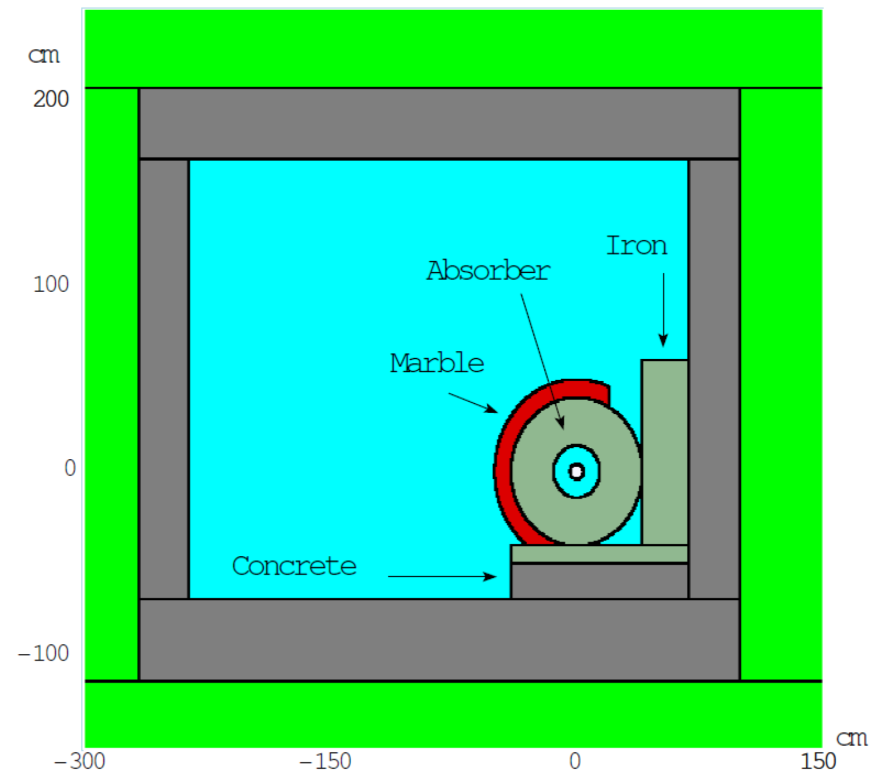
- 2% of H^- miss the foil → Q_1
- 1% of H^0 → absorber

Geometry

Plan view | Cross section

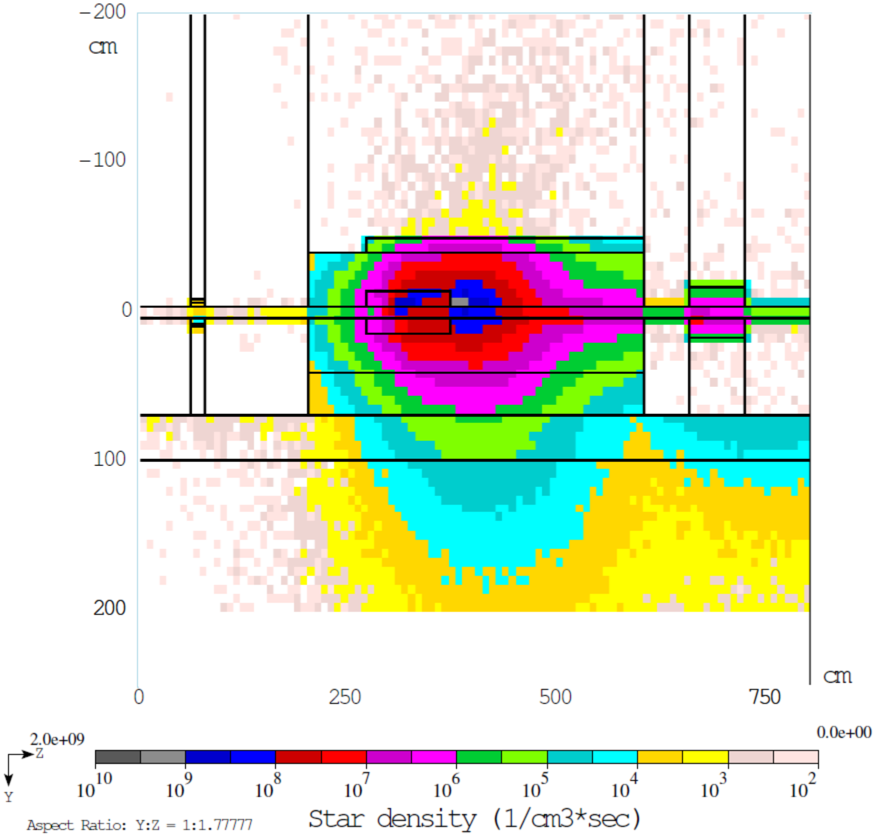
Steel absorber with inner radiation trap (R_{in}=4cm/14cm, R_{out}=40cm, L=400cm) ≈ 15300 kg
Concrete block under absorber (18cm x 108cm x 400 cm) ≈ 1900 kg
Steel plate to the right of absorber (100cm x 28cm x 400 cm) ≈ 8900 kg
Steel plate under the absorber (10cm x 108cm x 400 cm) ≈ 3400 kg
Marble layer ≈ 1300 kg



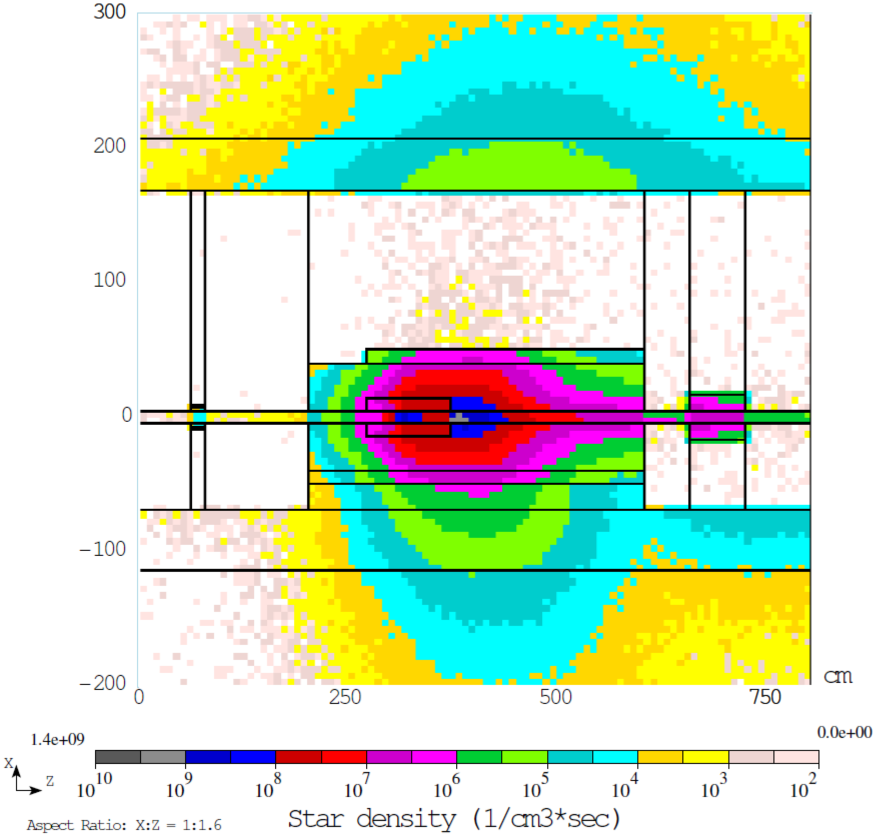


Calculated star density distributions

Plan view



Elevation view



Surface water activation (using sump pumps)

- **Groundwater** activation takes more time and requires analysis of geological structures (K. Vaziri).

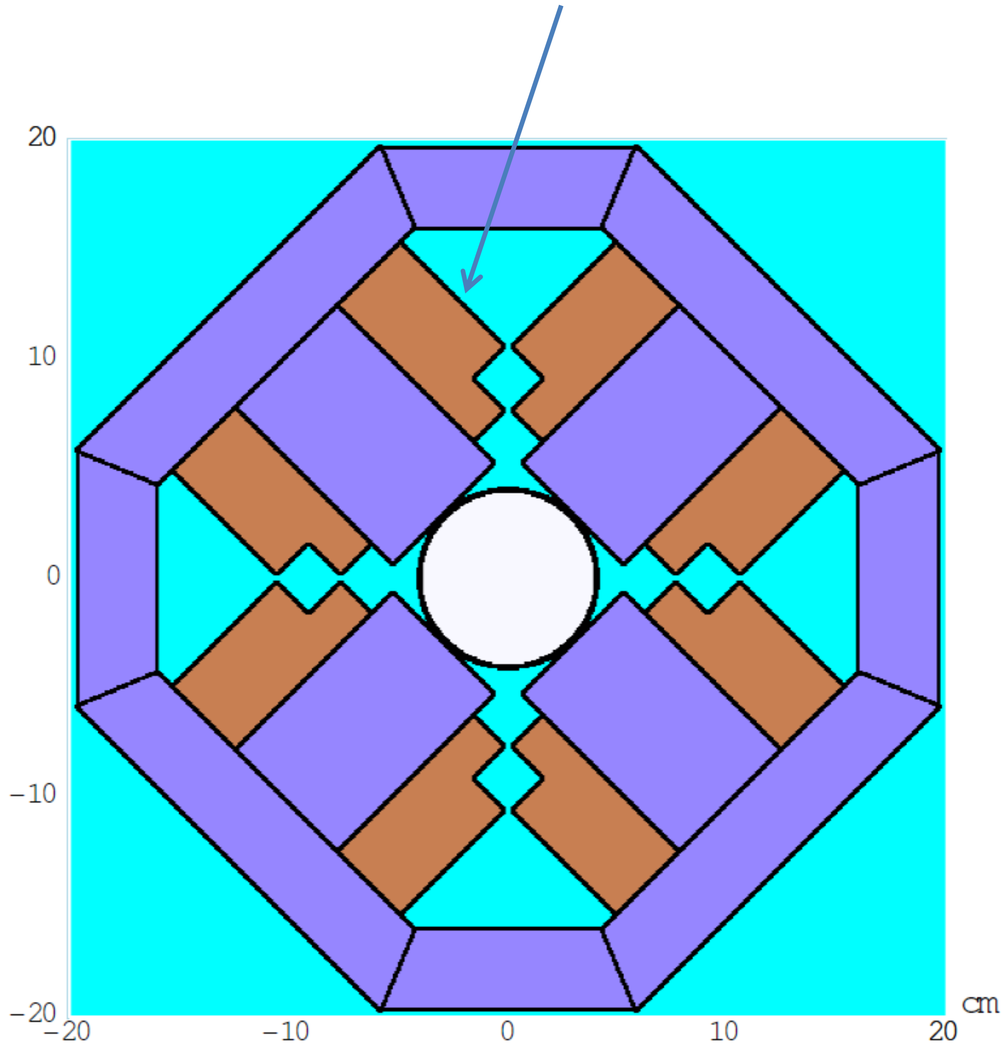
- For this beam absorber and shielding composition the calculated $S_{max} \approx 1.07E5$ star/cm^3*sec

- According to Concentration Model it means the surface water gets activated to the permitted max in about **6 months** → removal of activated water 2 times a year. **Common practice is to do that once a year.**

Absorbed dose in magnet coils

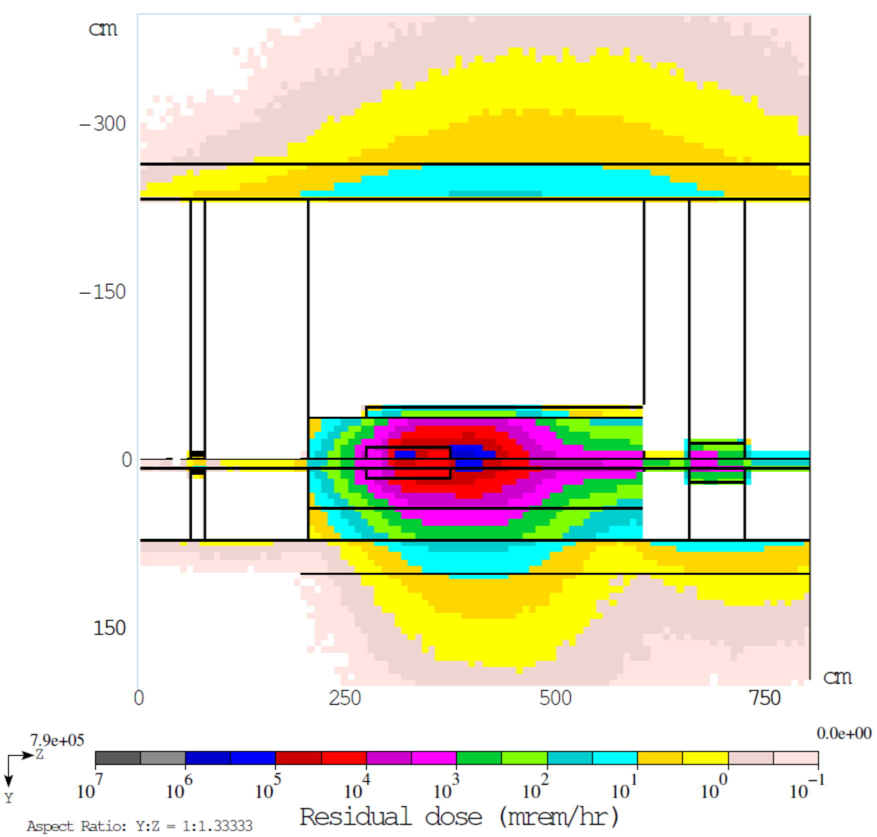
Usually **epoxy** can survive absorbed dose up to 400 Mrad = 4 MGy

Dipole → ≈ **100 yrs**
Quad → 0.6 MGy/yr → **7 yrs**

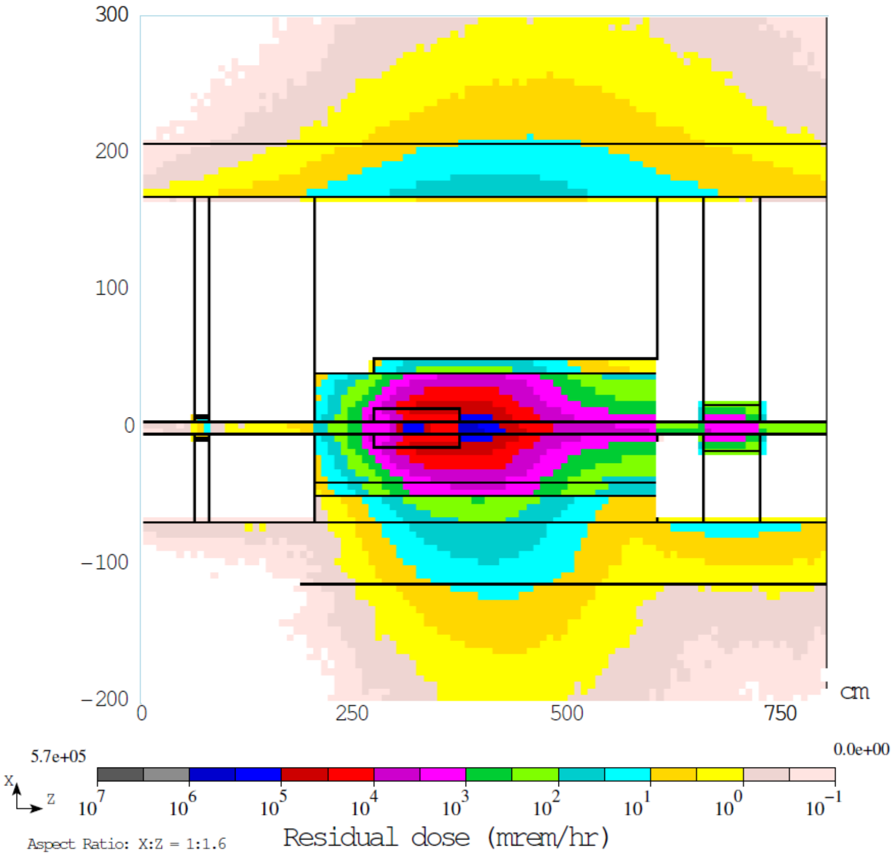


Residual dose (it is good to have it ≈ 100 mrem/hr)

Plan view



Elevation view



Conclusions

- Foil heating without taking into account heat conduction is too high (**≈2350 K**). **ANSYS** calculations should provide more realistic data.

- Surface water activation can be reduced by means of absorber/shielding optimization. **With current design**, removal of activated water can be required **two times a year**.

- Residual activation: The beam line components, both absorber and the 1st quad downstream, reveal some hot spots with $D_{max} \approx 10^3$ mrem/hr. The problem can be mitigated with **extra marble shielding** applied to the downstream end of the absorber and upstream end of the quad.

- The 1st quad downstream of the absorber **(epoxy in its coils)** will survive for about **7 years**. The lifetime can be increased by means of further increase of length of the absorber.